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(54)【発明の名称】光学的ローパスフイルタ

(57)【特許請求の範囲】

1．水平画素間隔Pxが垂直画素間隔Pyに略等しい関係にある固体撮像素子に使用される光学的ローパスフィルタであって、

上記固体撮像素子の水平走査方向に対して略45度の角度で距離d1だけ常光成分と異常光成分とを分離する第１の複屈折板と、上記水平走査方向に対して略平行に距離d2だけ常光成分と異常光成分とを分離する第２の複屈折板と、上記水平走査方向に対して略－45度の角度で距離d1だけ常光成分と異常光成分とを分離する第３の複屈折板とよりなり、上記第２の複屈折板が中間に位置するように、上記第1,第2,第３の複屈折板が積層配置され、且つ前記常光成分と異常光成分の分離距離d1及びd2と前記固体撮像素子の水平画素間隔Pxの関係が、

$$d2 > Px \quad \text{但し} \quad d2 \fallingdotseq Px \quad \text{且つ}$$

$$2 \cdot (\sqrt{2} \cdot d2) / 3 \leqq d1 < \sqrt{2} \cdot d2$$

の関係にあることを特徴とする光学的ローパスフィルタ。

2．水平画素間隔Pxが垂直画素間隔Pyに略等しい関係にある固体撮像素子に使用される光学的ローパスフィルタであって、

上記固体撮像素子の水平走査方向に対して略45度の角度で距離d1だけ常光成分と異常光成分とを分離する第１の複屈折板と、上記水平走査方向に対して略平行に距離d2だけ常光成分と異常光成分とを分離する第２の複屈折板と、上記水平走査方向に対して略－45度の角度で距離d1

だけ常光成分と異常光成分とを分離する第３の複屈折板とよりなり、上記第２の複屈折板が中間に位置するように、上記第1,第2,第３の複屈折板が積層配置され、且つ前記常光成分と異常光成分の分離距離d1及びd2と前記固体撮像素子の水平画素間隔Pxの関係が、

$$d2 > Px \quad 但し \quad d2 \fallingdotseq Px \quad 且つ$$

$$d1 \fallingdotseq 2 \cdot (\sqrt{2} \cdot d2) / 3$$

の関係にあることを特徴とする光学的ローパスフィルタ。

【発明の詳細な説明】

産業上の利用分野

本発明は、２次元のサンプリングを行なうCCDなどの固体撮像素子の入射光路中に配置され、キャリア成分の影響を抑圧する光学的ローパスフィルタに関する。

従来の技術

第５図は、固体撮像素子の画素配列及び開口例を示すもので、同図において、Ｈが水平走査方向、Ｖが垂直走査方向を示す。隣接する２本の水平ラインの一方には、緑色フィルタ1G及び青色フィルタ1BがP_xの水性走査方向の画素間隔で交互に配され、その他方には、緑色フィルタ2G及び赤色フィルタ2RがP_xの間隔で交互に配される。この垂直走査方向の画素間隔がP_yとされる。このような格子状の開口パターンにより被写体光がサンプリングされるわけであるが、サンプリング定理において明らかなように、サンプリング周波数の1/2の周波数以上の周波数成分は原理的に忠実にサンプリングして再現することができず、これ以上の周波数成分が固体撮像素子上に導かれると、偽信号となって現われることとなる。

上述の固体撮像素子の場合には、第６図の空間周波数スペクトラムに示すように、（fx=0,fy=０）の位置を中心とするベースバンド成分（2G,R,Bのベクトルで示す）の他に、複数の有害なキャリア成分が発生する。第６図の横軸f_x,縦軸f_yは、各々$P_x/2\pi$及び$P_y/2\pi$により正規化された水平周波数及び垂直周波数を表わしている。（f_x =1, f_y =０）の位置を中心として生じるキャリア成分は、垂直方向に延びる黒白のストライプからなるきめ細かい縞模様の時にモアレを生じさせ、（f_x =1/2, f_y =０）の位置を中心として生じるキャリア成分は、やや荒い縦ストライプ時に、緑色及びマゼンタが生じるクロスカラー現象（偽色信号）を生じさせ、この偽信号は単板でカラー信号を得ることによって生じるもので画質に与える影響が最も大きい。（f_x =0, f_y =１）の位置を中心として生じるキャリア成分は、細かい横ストライプの時にモアレを生じさせる。

したがって、これらの有害なキャリア成分を除去するためには、サンプリング定理に従って、入射光のうち、正規化水平周波数でf_x =1/2以上の水平周波数成分、及び正規化垂直周波数でf_y =1/2以上の垂直周波数成分を除去する必要がある。更に、色信号は水平方向のfx

=1/2の周波数がサンプリング周波数となる為、f_x =1/2の点を中心に色信号の周波数帯域分の水平周波数成分を除去する必要がある。このような理想的な光学的周波数特性を第７図に示す。同図で（Ａ）は水平周波数特性、（Ｂ）は垂直周波数特性を表わす。

このような特性を目標とした光学的ローパスフィルタの従来例としては、特開昭60－164719号に示されるものがある。これは、固体撮像素子の水平走査方向に対して、45度近傍で常光成分と異常光成分とを分離する第１の複屈折板と、水平走査方向と平行に常光成分と異常光成分とを分離する第２の複屈折板と、水平走査方向に対して、－45度近傍で常光成分とを分離する第３の複屈折板よりなり、第２の複屈折板が中間に位置するように、第１の複屈折板、第２の複屈折板及び第３の複屈折板が積層配置され、１本の入射光を７もしくは８本に分離する光学的ローパスフィルタの基本的な技術を示したものであるが、実施例としては第1,第2,第３の複屈折板による常光成分と異常光成分との分離距離（それぞれ、d_1,d_2,d_3とする）の関係が、

$$d_2 \simeq P_x で且つ d_1 \simeq d_3 \simeq d_2/\sqrt{2}$$

の関係にある例しか示されていない。このような従来の光学的ローパスフィルタによっては、１本の入射光は第８図に示すように分離され、その周波数特性は第９図に示すようになる。第９図において（Ａ）は水平方向の周波数特性を示し、同図91の曲線で示すf_x =1/2,3/2……にトラップポイントを有するcosカーブと、同図92の曲線で示すf_x =1,3,……にトラップポイントを有するcos' カーブを合成した曲線93が総合の水平方向の通過特性となる。また第９図において（Ｂ）は垂直方向の周波数特性を示すが、f_y =P_y/P_xの奇数倍の周波数にトラップポイントを有するcos' カーブ（同図94の曲線）が垂直方向の通過特性となる。

発明が解決しようとする問題点

上述した従来の光学ローパスフィルタの通過特性のうち、水平方向の特性は本来遮断すべき周波数成分は遮断されていて第７図（Ａ）に示した理想特性に近い特性が得られているが、垂直方向の特性には次のような問題点がある。

第８図にように分離された１本の入射光の垂直方向の分離距離は、Pxを基準としたものであり、画素の水平方向間隔P_xにより決定されていて、画素の垂直方向間隔P_yによっては決定されていない。したがって垂直方向の周波数特性の通過特性のトラップポイントは理想値が1/2であるのに対し$P_y/2\pi$で正規化した垂直周波数のP_y/P_xの点（及びその奇数倍の周波数）となり、P_xとP_yの関係によってトラップ点が変化することとなる。したがってP_y/P_xが1/2に近い値をとる固体撮像素子では、上述した従来の光学的ローパスフィルタでは必要な垂直方向通過特性が得られるが、P_xが$2P_y$より小さくなってP_y/P_xが1/

2と大きく異なる値となる固体撮像素子用には必要な特性が得られなくなる。このような状態は、水平解像度を上げる為に水平方向の画素数を多くした固体撮像素子において発生する。つまり、垂直方向の画素数n_vがテレビジョン方式に基ずいて決定される値（NTSC方式では約500画素・PAL方式では約600画素）に固定されているためP_vが一定であるのに対し、P_hは水平方向画素数n_Hの変化により変化し、したがってn_Hが多くなるとP_v/P_hは大きくなる。例えばNTSC方式で水平方向画素数が670画素の場合には、テレビジョン画面の縦・横比が3:4（≃500:670）であるので、$P_h \simeq P_v$となる。このような場合の、従来の光学ローパスフィルタの垂直方向の通過特性は、第10図101の曲線に示す特性となり、同図102の曲線に示す理想特性との遮断周波数域の低周波数領域での特性差が大きくなり、偽信号が大きくなる。なお、遮断周波数域の低周波数領域での特性を重視するのは、一般に、

（１）被写体光の周波数成分は高域ほど少ない。

（２）レンズの空間周波数特性は高域ほど小さい。

という性質を有している為である。（ちなみに、水平画素数が約400と少ない場合いは、$P_v/P_h = 3/500/4/400 \simeq 0.6$となりこの場合の特性は同図103の曲線となり、遮断域の低周波数領域での理想特性との差は少なく、従来の光学的ローパスフィルタで十分な特性が得られている。）

以上述べたように、従来の光学的ローパスフィルタでは、水平画素数の多い固体撮像素子に使用したときには、垂直方向の周波数特性に必要な特性が得られず、細かい横ストライプを撮影したときに大きな偽信号が発生するという問題点がある。

問題点を解決するための手段

上述した問題点を解決するために、第１の発明は、水平画素間隔Pxが垂直画素間隔Pyに略等しい関係にある固体撮像素子に使用される光学的ローパスフィルタであって、前記固体撮像素子の水平走査方向に対して略45度の角度で距離d1だけ常光成分と異常光成分とを分離する第１の複屈折板と、上記水平走査方向に対して平行に距離d2だけ常光成分と異常光成分とを分離する第２の複屈折板と、上記水平走査方向に対して略−45度の角度で距離d1だけ常光成分と異常光成分とを分離する第３の複屈折板とよりなり、上記第２の複屈折板が中間に位置するように、上記第1,第2,第３の複屈折板が積層配置され、かつ前記常光成分と異常光成分の分離距離d1及びd2と前記固体撮像素子の水平画素間隔Pxの関係が、

$$d2 > Px \quad \text{但し} \quad d2 \fallingdotseq Px \quad \text{かつ}$$

$$2\cdot(\sqrt{2}\cdot d2)/3 \leqq d1 < \sqrt{2}\cdot d2$$

の関係にあることを特徴とする光学的ローパスフィルタである。

また第２の発明は、水平画素間隔Pxが垂直画素間隔Pyに略等しい関係にある固体撮像素子に使用される光学的ローパスフィルタであって、前記固体撮像素子の水平走査方向に対して略45度の角度で距離d1だけ常光成分と異常光成分とを分離する第１の複屈折板と、前記水平走査方向に対して平行に距離d2だけ常光成分と異常光成分とを分離する第２の複屈折板と、上記水平走査方向に対して略−45度の角度で距離d1だけ常光成分と異常光成分とを分離する第３の複屈折板とよりなり、上記第２の複屈折板が中間に位置するように、上記第１、第２、第３の複屈折板が積層配置され、かつ前記常光成分と異常光成分の分離距離d1及びd2と前記固体撮像素子の水平画素間隔Pxの関係が、

$$d2 > Px \quad \text{但し} \quad d2 \fallingdotseq Px \quad \text{かつ}$$

$$d1 \fallingdotseq 2\cdot(\sqrt{2}\cdot d2)/3$$

の関係にあることを特徴とする光学的ローパスフィルタである。

作用

本発明は、上記した構成の光学的ローパスフィルタで、固体撮像素子の水平画素間隔P_hと垂直画素間隔P_vとの関係がP_v/P_hの値が1/2と大きく異なる場合にも、水平方向のみならず垂直方向の周波数特性も理想特性に近い値を達成して、偽信号の発生の少ない固体撮像カメラを達成するものである。

実施例

以下本発明の一実施例について図面を参照して説明する。第１図は、この一実施例における第１の複屈折板11,第２の複屈折板12,第３の複屈折板13の光学的特性の説明に用いるものである。同図において、レンズを介された入射光は、図面の用紙面に直交する方向で複屈折板11,12,13に供給される。複屈折板11は、入射光を常光線及び異常光線に分離し、これらの常光線及び異常光線が存在する図面の用紙面と垂直に延びる主要面14が水平走査方向Ｈに対して略45度の角度をなすものである。複屈折板12は、常光線及び異常光線が存在する主要面15が水平走査方向と略一致するものである。複屈折板13は、その主要面16が水平走査方向Ｈに対して略−45度の角度をなすものである。これら３個の複屈折板11,12,13は第２の複屈折板12が中間に位置するように積層され、第１もしくは第３の複屈折板が固体撮像素子に最も近い位置に来るように入射光路中に配される。なお、以降の説明は第３の複屈折板が固体撮像素子に最も近い位置に配されているとして説明を行なう。また、３枚の複屈折板11,12,13の主要面の互いのなす角度は、相対的なものであり、角度の計測方法は時計回り，反時計回りいずれであっても良い。

次に本実施例における３枚の複屈折板によって入射光

が分離される分離距離の一般解について説明する。

いま第1及び第3の複屈折板による常光線と異常光線の分離距離をd_1，第2の複屈折板による常光線と異常光線の分離距離をd_2とし、

$$\frac{d_2}{\sqrt{2}} < d_1 < \sqrt{2}\,d_2$$

の条件にあるときに、この3枚の複屈折板の上記した組み合わせによる入射光の分離された結果は第2図に示ようにになる。つまり、第2図の原点に入射された1本の光は、第1の複屈折板11により、水平走査方向に対し45度の方向に距離d_1だけ分離され、（第2図の実線の矢印で示す。）おのおの等しい強度の2本の光線となる。次にこれらの光線は第2の複屈折板12によって、おのおの水平走査方向に対して平行に距離d_2だけ分離され（第2図の破線の矢印で示す。）、おのおのの等しい強度を有する4本の光線となる。次にこれら4本の光線は第3の複屈折板13によって、おのおの水平走査方向に対して－45度の方向に距離d_1だけ分離され（第2図の一点鎖線の矢印で示す。）、最終的に第2図に示すような、おのおのの強度の等しい21～28の8本の光線に分離される。

以上のような実施例は、第3図（A）に示すような水平方向Hにd_2の距離だけ常光線と異常光線を分離する光学的ローパスフィルタと、第3図（B）に示すような、1本の光線を

$$d_1/\sqrt{2}$$

の長さのひし形の頂点の位置の4本の光線に分ける光学的ローパスフィルタとを合成したものとして考えられる。第3図（A）に示す光学的ローパスフィルタは、$P_x/2\pi$で正規化した水平周波数の

$$\frac{1}{2}\cdot\frac{P_x}{d_2}\ (=f_{x\infty 1})$$

の奇数倍の点にトラップポイントを有するcosカーブの周波数特性を有し、第3図（B）に示す光学的ローパスフィルタは、水平方向には

$$\frac{1}{2}\cdot\frac{P_x}{d_1/\sqrt{2}}\ (=f_{x\infty 2})$$

の奇数倍の点にトラップポイントを有する$\cos^2$カーブの周波数特性を有し、垂直方向には、

$$\frac{1}{2}\cdot\frac{P_y}{d_1/\sqrt{2}}\ (=f_{y\infty 1})$$

の奇数倍の点にトラップポイントを有する$\cos^2$カーブの周波数特性を有している。したがって、上記実施例の光学的ローパスフィルタの水平方向の周波数特性は

$$\cos\cdot\frac{f_x}{f_{x\infty 1}}\cdot\frac{\pi}{2}\times\cos^2\frac{f_x}{f_{x\infty 2}}\cdot\frac{\pi}{2}$$

の特性となり、垂直方向には

$$\cos^2\frac{f_y}{f_{y\infty 1}}\cdot\frac{\pi}{2}$$

の周波数特性を有することとなる。

次にこの実施例において、従来例の問題点の項で引用したような、P_xとP_yが略等しい場合に、望ましい水平及び垂直周波数特性が得られるように、d_1及びd_2の値を決定した場合の特性について述べる。

いま

$$d_2 = P_x,\quad d_1/\sqrt{2} = \frac{2}{3}\cdot P_x$$

とすると、（したがって、

$$d_1 = \frac{2\sqrt{2}}{3}\cdot d_2 = 0.943\,d_2$$

であり従来例の

$$d_1 = d_2/\sqrt{2} = 0.707\,d_2$$

とは大きく異なる）

$$f_{\infty x1} = 1/2,\quad f_{\infty x2} = \frac{1.5}{2},\quad f_{\infty y2} = \frac{1.5}{2}$$

となり、水平方向の周波数特性は、第4図（A）の曲線42に示す

$$\cos\frac{f_x}{f_{x\infty 1}}\cdot\frac{\pi}{2}$$

の曲線と、43に示す

$$\cos^2\frac{f_x}{f_{x\infty 1}}\cdot\frac{\pi}{2}$$

の曲線を合成した、曲線41の特性となり、曲線44に示す従来例（$d_2=P_x$，

$$d_1 = d_2/\sqrt{2}\ )$$

の特性（第9図（A）曲線93を再掲）と同じく曲線40に示す理想特性（第7図（A）の曲線を再掲）に近い遮断特性が得られている。

また、垂直方向の周波数特性は、第4図（B）の曲線51に示す特性となり、同図曲線52に示す従来例の特性（第10図曲線101を再掲）に比して、同図曲線50に示す理想特性に近い特性となっている。

以上の例の一般解について考察する。本発明では、従来例のように、

$$d_1 = d_2/\sqrt{2} = P_x/\sqrt{2}$$

に固定、したがって、

$$f_{x\infty 2} = 2 \cdot f_{x\infty 1},\ f_{y\infty 1} = \frac{P_y}{P_x} \cdot 2 f_{x\infty 1}$$

に固定されるのではなく、d_1 を P_x の値をも考慮して決定して、$f_{x\infty 1} < f_{x\infty 2} < 2 \cdot f_{x\infty 1}$ の値とし、したがって

$$f_{y\infty 1} = \frac{P_y}{P_x} \cdot f_{x\infty 2} < \frac{P_y}{P_x} \cdot 2 f_{x\infty 1}$$

とすることができ、垂直方向の周波数特性を理想特性に近い値とすることができ、水平・垂直双方の周波数特性ともに良好な特性が得られる。

なお一般解として、d_1 の値の望ましい範囲は次のとおりである。つまり $f_{x\infty 2}$ を、$f_{x\infty 1}$ より近さな値に設定すると、水平方向の周波数特性の本来通過させるべき周波数領域での特性が劣化し（通過パワーが小さくなりすぎる）してしまうので、$1/2 = f_{x\infty 1} < f_{x\infty 2}$ の値に設定するのが現実的である。

この条件を d_1, d_2, P_x の関係に書き改めると、

$$d_1 < \sqrt{2}\, d_2 \simeq \sqrt{2}\, P_x$$

となる。また、従来例の説明の項で説明したように、従来例のように $f_{x\infty 2} = 2 \cdot f_{x\infty 1}$ とすると問題点が生じ、$f_{x\infty 2} < 2 \cdot f_{x\infty 1}$ とする必要があるので、この条件を含めた d_1, d_2, P_x の望ましい関係は

$$d_2/\sqrt{2} < d_1 < \sqrt{2}\, d_2 \simeq \sqrt{2}\, P_x$$

のようになる。

なお、以上の説明では $d_1 \simeq P_x$ したがって $f_{x\infty 1} = 1/2$ とした例を説明したが、この時に $f_{x\infty 2}$ が $f_{x\infty 1}$ に近くなると、水平方向の通過特性が劣化（通過パワーが小さくなる）しすぎるので、これを防止するには、$f_{x\infty 1}$ の値を1/2より少し大きくする（したがって d_1 を P_x より少し小さくする。）ことで、遮断特性をあまり劣化させることなく達成できる。

発明の効果

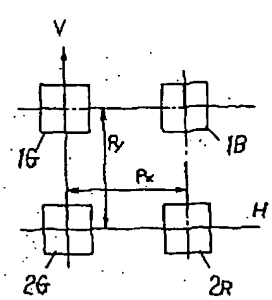
以上説明したように、本発明によれば、水平方向，垂直方向ともに良好な特性の光学的ローパスフィルタを得ることができ、特に従来例に比して垂直方向の特性を改良するとことができ、固体撮像カメラ、特に水平画素数が相対的に多い固体撮像素子を用いたカメラの画質を改善することができる。

【図面の簡単な説明】

第1図は本発明の一実施例に用いる各複屈折板の光学的特性の説明に用いる略構成図、第2図は本発明による入射光線の分離される様子を示す説明図、第3図は本実施例の光学的特性の説明図、第4図は本実施例の光学周波数特性図、第5図は本発明を適用するCCD固体撮像素子の開口パターンの一例の拡大平面図、第6図はこのCCD固体撮像素子により得られる空間周波数スペクトラム図、第7図はこのCCD固体撮像素子に必要な光学的ローパスフィルタの理想特性を示す特性図、第8図は従来の光学的ローパスフィルタによる光線分離の様子を示す説明図、第9図，第10図はこの従来例の光学的ローパスフィルタの周波数特性図である。

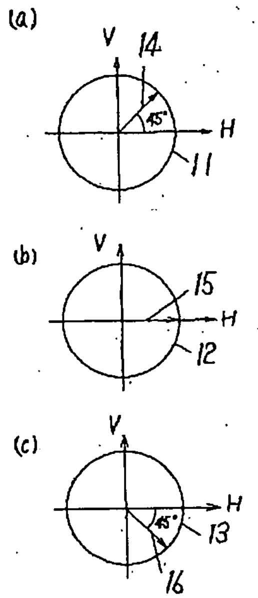
11……第1の複屈折板、12……第2の複屈折板、13……第3の複屈折板。

【第5図】



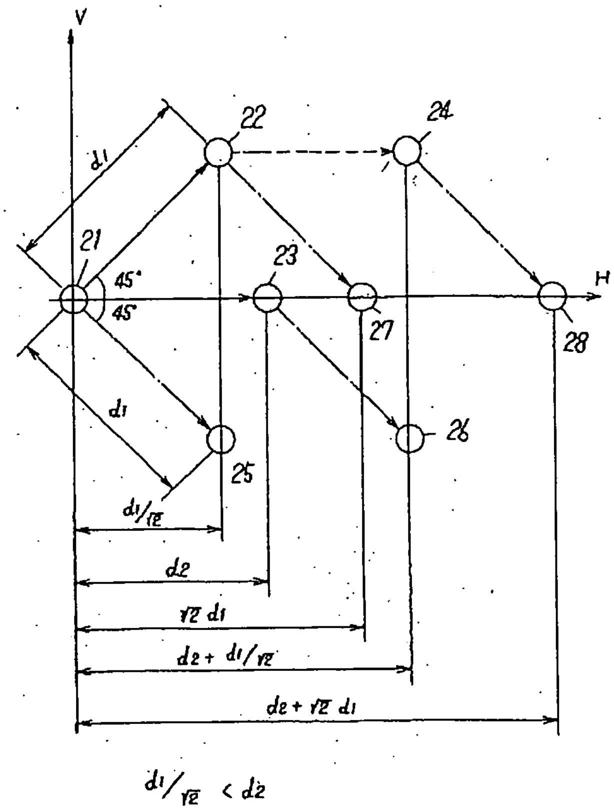
【第１図】

11 — オ1の複屈折板
12 … オ2の複屈折板
13 … オ3の複屈折板
14 … 主要面
15 — 主要面
16 … 主要面

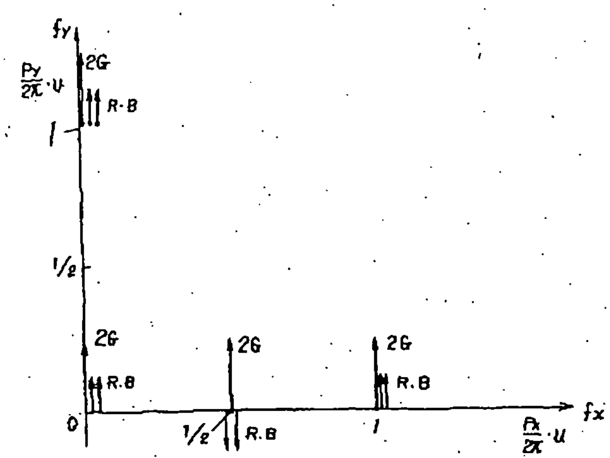


【第２図】

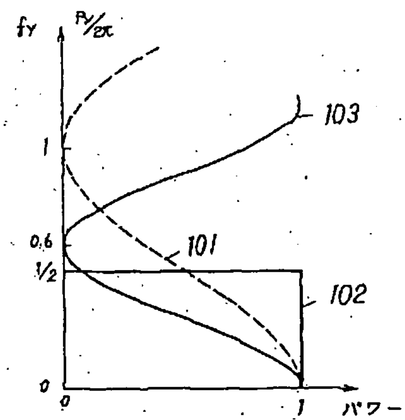
21~28 … 光線



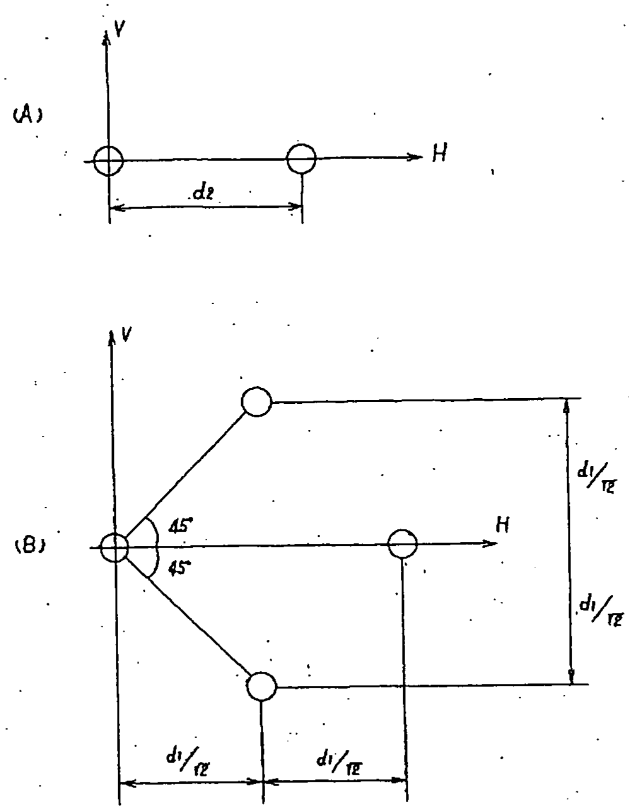
【第６図】



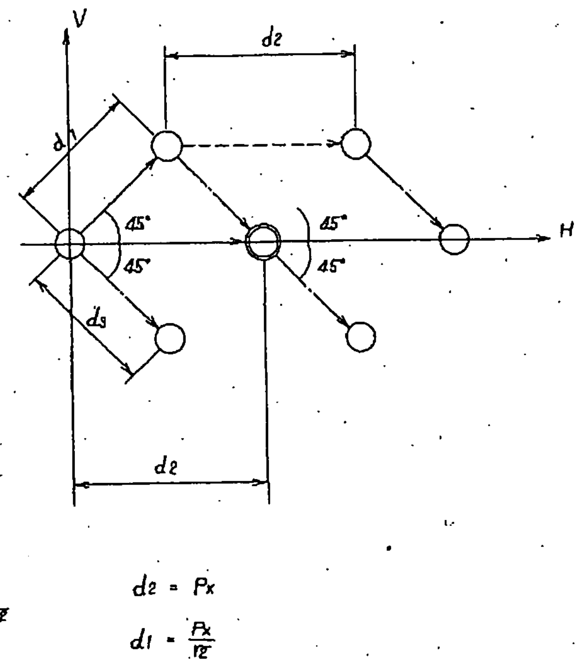
【第１０図】



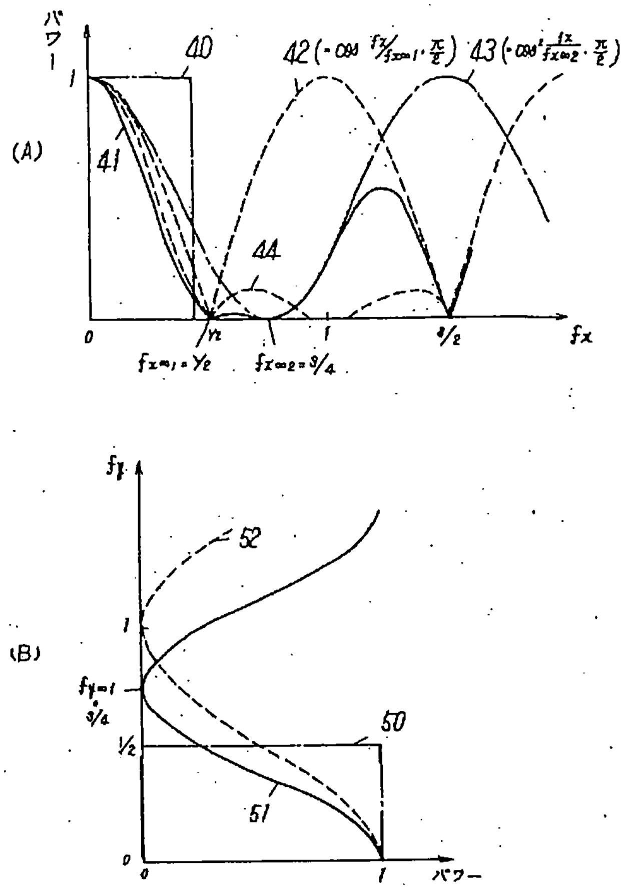
【第３図】


V
(A)
H
d2
V
(B)
45°
45°
H
d1/√2
d1/√2
d1/√2
d1/√2

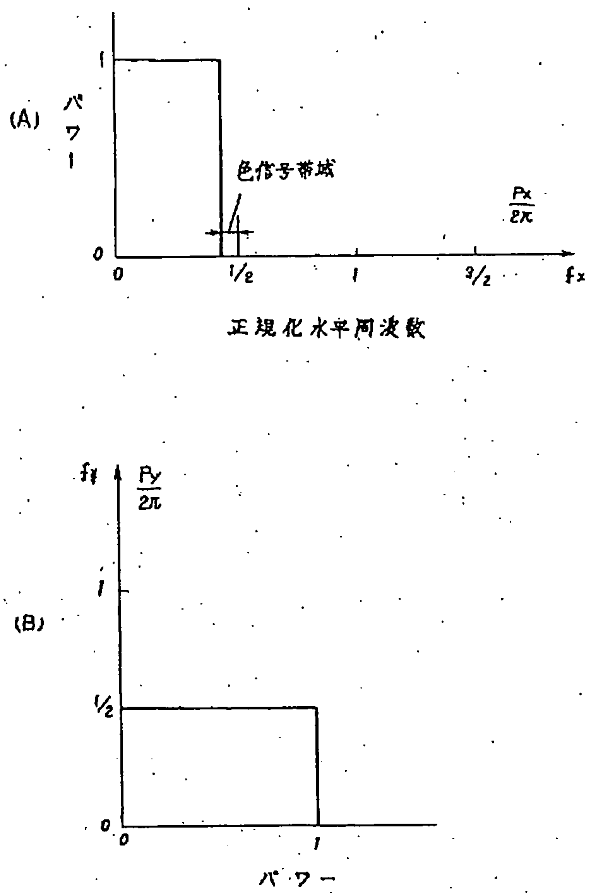
【第８図】


V
d2
d1
45°
45°
45°
45°
H
d3
d2
d2 = Px
d1 = Px/√2

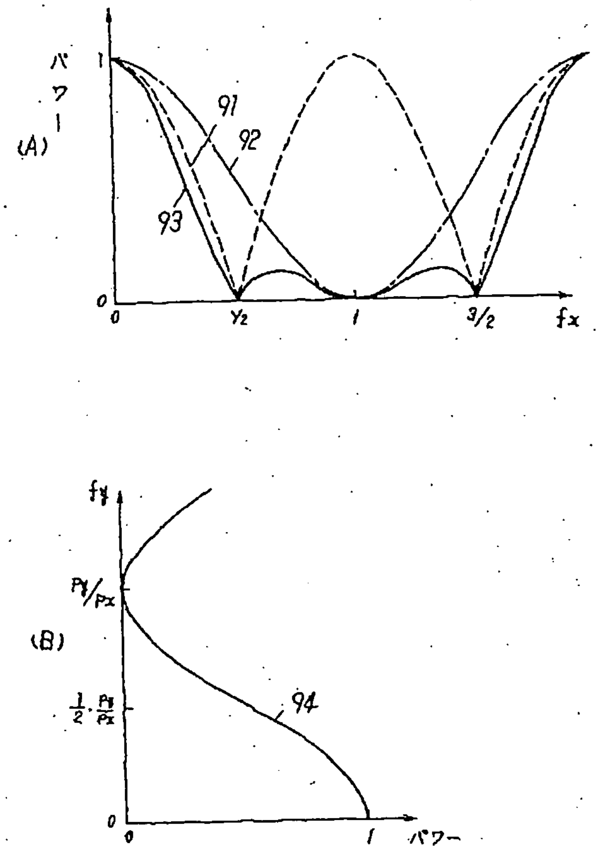
【第4図】


(A)
パワー
1
40
41
42
43
44
0
1/2
1
3/2
fx
fx∞1=1/2
fx∞2=3/4
(B)
fy
52
1
fy∞1
3/4
1/2
50
51
0
0
1
パワー

【第7図】


(A)
パワー
色信号帯域
Px/2π
0
1/2
1
3/2
fx
1
正規化水平周波数
(B)
fy
Py/2π
1
1/2
0
パワー

【第9図】


(A)
パワー
91
92
93
0
1/2
1
3/2
fx
(B)
fy
Py/Px
1/2・Py/Px
94
0
1
パワー

Date: March 25, 2004

Declaration

I, Michihiko Matsuba, President of Fukuyama Sangyo Honyaku Center, Ltd., of 16-3, 2-chome, Nogami-cho, Fukuyama, Japan, do solemnly and sincerely declare that I understand well both the Japanese and English languages and that the attached document in English is a full and faithful translation, of the copy of Japanese Patent No. 2840619 laid open on October 23, 1998.

M. Matsuba

Michihiko Matsuba

Fukuyama Sangyo Honyaku Center, Ltd.

OPTICAL LOW-PASS FILTER

Japanese Patent No. 2840619

Laid-open on: October 23, 1998

Application No. Sho-62-105161

Filed on: April 28, 1987

Applicant: Matsushita Electric Industrial Co., Ltd.

Inventor: Masaaki NAKAYAMA

Patent Attorney: Tomoyuki TAKIMOTO

SPECIFICATION

[TITLE OF THE INVENTION] Optical low-pass filter

[WHAT IS CLAIMED IS;]

1. An optical low-pass filter used for a solid-state image pickup element having a substantially equal relationship between a horizontal pixel-to-pixel distance P_x and a vertical pixel-to-pixel distance P_y, the optical low-pass filter comprising:

a first birefringent plate that separates an ordinary ray component and an extraordinary ray component from each other by distance d_1 substantially at an angle of 45 degrees

with respect to a horizontal scanning direction of the solid-state image pickup element, a second birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially in parallel with respect to the horizontal scanning direction by distance d_2, and a third birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially at an angle of -45 degrees with respect to the horizontal scanning direction by distance d_1, wherein the first, second , and third birefringent plates are arranged in layers so that the second birefringent plate is situated between the remaining birefringent plates, and a relationship among the separation distances d_1 and d_2 between the ordinary and extraordinary ray components and the horizontal pixel-to-pixel distance P_x of the solid-state image pickup element is established as follows:

$$d_2 > P_x, \text{ however, } d_2 \cong P_x, \text{ and, } 2 \bullet \left(\sqrt{2} \bullet d_2\right) / 3 \leq d_1 < \sqrt{2} \bullet d_2 .$$

2. An optical low-pass filter used for a solid-state image pickup element having a substantially equal relationship between a horizontal pixel-to-pixel distance P_x and a vertical pixel-to-pixel distance P_y, the optical

low-pass filter characterized by comprising:

a first birefringent plate that separates an ordinary ray component and an extraordinary ray component from each other by distance d_1 substantially at an angle of 45 degrees with respect to a horizontal scanning direction of the solid-state image pickup element, a second birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially in parallel with respect to the horizontal scanning direction by distance d_2, and a third birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially at an angle of -45 degrees with respect to the horizontal scanning direction by distance d_1, wherein the first, second, and third birefringent plates are arranged in layers so that the second birefringent plate is situated between the remaining birefringent plates, and a relationship among the separation distances d_1 and d_2 between the ordinary and extraordinary ray components and the horizontal pixel-to-pixel distance P_x of the solid-state image pickup element is established as follows:

$$d_2 > P_x, \text{ however, } d_2 \cong P_x, \text{ and, } d_1 \cong 2 \bullet \left(\sqrt{2} \bullet d_2\right) / 3 .$$

[DETAILED DESCRIPTION OF THE INVENTION]

Field of the Invention

The present invention relates to an optical low-pass filter that is disposed in an incidence optical path of a solid-state image pickup element, such as a CCD, performing two-dimensional sampling and that suppresses the influence of a carrier component.

Prior Arts

Fig. 5 shows an example of a pixel arrangement and an opening of a solid-state image pickup element, in which H denotes a horizontal scanning direction, and V denotes a vertical scanning direction. A green filter 1G and a blue filter 1B are alternately disposed at a pixel-to-pixel distance of P_x in the horizontal scanning direction on one of two adjoining horizontal lines, whereas a green filter 2G and a red filter 2R are alternately disposed at the distance of P_x on the other one. A pixel-to-pixel distance in a vertical scanning direction is denoted by P_y. Subject light is sampled by such a grid-like opening pattern, and, as is apparent in a sampling theorem, a frequency component greater than a frequency that is half a sampling frequency cannot be fundamentally accurately reproduced by sampling,

and, if a frequency component exceeding this is guided onto the solid-state image pickup element, it will appear as an alias.

In the aforementioned solid-state image pickup element, a plurality of deleterious carrier components occur in addition to baseband components (indicated by vectors of 2G, R, and B) that center on the position of (f_x=0, f_y=0), as shown in a spatial frequency spectrum of Fig. 6. Abscissa axis f_x and ordinate axis f_y of Fig. 6 indicate a horizontal frequency and a vertical frequency that have been normalized by $P_x/2\pi$ and $P_y/2\pi$, respectively. A carrier component generated centering on the position of (f_x=1, f_y=0) causes a moire when a fine striped pattern having black and white stripes extending in the vertical direction is formed, and a carrier component generated centering on the position of (f_x=1/2, f_y=0) causes a cross color phenomenon (false color signal) in which green and magenta are generated when slightly rough longitudinal stripes are formed. This alias is caused by obtaining a color signal with a single plate and is the largest in influence exerted upon image quality. A carrier component generated centering on the position of (f_x=0, f_y=1) causes a moire when fine horizontal stripes are

formed.

Therefore, in order to remove these deleterious carrier components, there is a need to, among incident light, remove a horizontal frequency component of $f_x=1/2$ or more, which is a normalized horizontal frequency, and a vertical frequency component of $f_y=1/2$ or more, which is a normalized vertical frequency, in accordance with the sampling theorem. Further, in a color signal, a frequency of $f_x=1/2$ in the horizontal direction serves as a sampling frequency, and therefore there is a need to remove a horizontal frequency component for a frequency band of the color signal, centering on the point of $f_x=1/2$. Under such an ideal, optical frequency characteristics are shown in Fig. 7. In this figure, (A) shows a horizontal frequency characteristic, and (B) shows a vertical frequency characteristic.

An example disclosed in Japanese Unexamined Patent Publication No. Sho-60-164719 can be mentioned as a conventional optical low-pass filter that aims to have these characteristics. This shows a basic technique of an optical low-pass filter that comprises a first birefringent plate that separates an ordinary ray component and an extraordinary ray component from each other in the vicinity of 45 degrees

with respect to the horizontal scanning direction of a solid-state image pickup element, a second birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other in parallel with the horizontal scanning direction, and a third birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other at about -45 degrees with respect to the horizontal scanning direction and in which the first, second, and third birefringent plates are arranged in layers so that the second birefringent plate is situated between the remaining birefringent plates, and one incident beam of light is separated into seven or eight rays of light. What has been shown as an embodiment is only an example having a relationship among separation distances (referred to as d_1, d_2, and d3, respectively) between the ordinary ray component and the extraordinary ray component by the first, second, and third birefringent plates, the relationship being expressed as

$$d_2 \simeq P_x, \text{ and, } d_1 \simeq d_3 \simeq d_2 / \sqrt{2}$$

According to the conventional optical low-pass filter formed in this way, the one incident beam of light is separated as shown in Fig. 8, and its frequency characteristics are as

shown in Fig. 9. In Fig. 9, (A) indicates a horizontal frequency characteristic, and a curve 93 obtained by a combination of a cos curve that has trap points at $f_x=1/2$, 3/2...... shown by a curve 91 of the figure and a $\cos^2$ curve that has trap points at $f_x=1$, 3, ... shown by a curve 92 of the figure is a total passing characteristic in the horizontal direction. Further, in Fig. 9, (B) indicates a frequency characteristic in the vertical direction, and a $\cos^2$ curve (curve 94 of this figure) that has trap points at odd-number times as large a frequency as $f_y=P_y/P_x$ is a passing characteristic in the vertical direction.

Problems to be Solved by the Invention

Among the passing characteristics of the conventional optical low-pass filter mentioned above, the characteristic in the horizontal direction is characterized in that a frequency component, which should be originally blocked, is blocked and wherein a characteristic near the ideal characteristic shown in Fig. 7 (A) is obtained, the characteristic in the vertical direction has the following problem.

A separation distance in the vertical direction of one incident beam of light separated as shown in Fig. 8 is based

on P_x and is determined by a pixel-to-pixel distance in the horizontal direction, not by a pixel-to-pixel distance in the vertical direction P_y. Therefore, the trap point of the passing characteristic of a frequency characteristic in the vertical direction has an ideal value of 1/2, but is a point of P_y/P_x of a vertical frequency normalized by $P_y/2\pi$ (and odd-number times as large a frequency as it), and, accordingly, the trap point changes depending on the relationship between P_x and P_y. Therefore, in the conventional optical low-pass filter mentioned above, a necessary passing characteristic in the vertical direction can be obtained for a solid-state image pickup element in which P_y/P_x takes a value near 1/2, but a necessary characteristic cannot be obtained for a solid-state image pickup element in which P_x becomes smaller than $2P_y$ so that P_y/P_x takes a value greatly different from 1/2. Such a state occurs in a solid-state image pickup element in which the number of pixels in the horizontal direction is increased in order to heighten a horizontal resolution. In other words, since the number nV of pixels in the vertical direction is fixed at a value (in the NTSC standard, about 600 pixels in an about 500-pixel PAL system) that is determined based on

a television system, P_y is constant, but P_x changes in accordance with a variation in the number nH of pixels in the horizontal direction, and, accordingly, P_y/P_x becomes larger proportionately with a rise in nH. For example, when the NTSC standard is employed, and the number of pixels in the horizontal direction is 670, an vertical/horizontal ratio of a television screen is 3:4 ($\simeq$ 500:670), and therefore $P_x \simeq P_y$. A passing characteristic in the vertical direction of the conventional optical low-pass filter in this case is a characteristic shown by a curve designated by 101 in Fig. 10, and a characteristic difference in a low frequency area of a cutoff frequency band with respect to an ideal characteristic shown by a curve designated by 102 in the figure becomes large, and an alias becomes large. The reason why much importance is attached to the low frequency area of the cutoff frequency band is that, generally, there are properties wherein:

(1) A frequency component of subject light becomes smaller proportionately as the frequency area becomes higher, and

(2) A spatial frequency characteristic of a lens becomes smaller proportionately as the frequency area becomes higher.

(In this connection, when the number of pixels in the horizontal direction is about 400, which is a small case, $P_y/P_x = 3/500/4/400 \simeq 0.6$, and a characteristic in this case is shown by the curve 103 of Fig. 10, in which a difference in the low frequency area of the cutoff frequency band with respect to the ideal characteristic is small, and in which a sufficient characteristic is obtained by the conventional optical low-pass filter.)

As described above, the conventional optical low-pass filter cannot obtain a characteristic needed for a frequency characteristic in the vertical direction when it is used in a solid-state image pickup element large in the number of pixels in the horizontal direction, and therefore, disadvantageously, a large alias occurs when fine horizontal stripes are photographed.

Means for Solving Problems

In order to solve the aforementioned problems, a first invention is an optical low-pass filter used for a solid-state image pickup element having a substantially equal relationship between a horizontal pixel-to-pixel distance P_x and a vertical pixel-to-pixel distance P_y, and the optical low-pass filter is characterized by comprising:

a first birefringent plate that separates an ordinary ray component and an extraordinary ray component from each other by distance d_1 substantially at an angle of 45 degrees with respect to a horizontal scanning direction of the solid-state image pickup element, a second birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially in parallel with the horizontal scanning direction by distance d_2, and a third birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially at an angle of -45 degrees with respect to the horizontal scanning direction by distance d_1, wherein the first, second , and third birefringent plates are arranged in layers so that the second birefringent plate is situated between the remaining birefringent plates, and a relationship among the separation distances d_1 and d_2 between the ordinary and extraordinary ray components and the horizontal pixel-to-pixel distance P_x of the solid-state image pickup element is established as follows:

$$d_2 > P_x, \textit{ however, } d_2 \cong P_x, \textit{ and, } 2 \bullet \left(\sqrt{2} \bullet d_2\right) / 3 \leq d_1 < \sqrt{2} \bullet d_2 .$$

Further, a second invention is an optical low-pass filter used for a solid-state image pickup element having

a substantially equal relationship between a horizontal pixel-to-pixel distance P_x and a vertical pixel-to-pixel distance P_y, and the optical low-pass filter is characterized by comprising: a first birefringent plate that separates an ordinary ray component and an extraordinary ray component from each other by distance d_1 substantially at an angle of 45 degrees with respect to a horizontal scanning direction of the solid-state image pickup element, a second birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially in parallel with the horizontal scanning direction by distance d_2, and a third birefringent plate that separates the ordinary ray component and the extraordinary ray component from each other substantially at an angle of -45 degrees with respect to the horizontal scanning direction by distance d_1, wherein the first, second, and third birefringent plates are arranged in layers so that the second birefringent plate is situated between the remaining birefringent plates, and a relationship among the separation distances d_1 and d_2 between the ordinary and extraordinary ray components and the horizontal pixel-to-pixel distance P_x of the solid-state image pickup element is established

as follows:

$$d_2 > P_x, \text{ however, } d_2 \cong P_x, \text{ and, } d_1 \cong 2 \bullet \left(\sqrt{2} \bullet d_2\right) / 3 .$$

Actions

The present invention is an optical low-pass filter constructed as above, and, even when a relationship between a horizontal pixel-to-pixel distance P_x and a vertical pixel-to-pixel distance P_y of a solid-state image pickup element has a great difference in which P_y/P_x is 1/2, the frequency characteristic not only in the horizontal direction but also in the vertical direction achieves a value near an ideal characteristic, thereby achieving a solid-state image pickup camera in which the occurrence of an alias is small.

Embodiment

An embodiment of the present invention will be hereinafter described with reference to the drawings. Fig. 1 is to be used to explain optical properties of a first birefringent plate 11, a second birefringent plate 12, and a third birefringent plate 13 in this embodiment. In this figure, incident light through a lens is supplied to the birefringent plates 11, 12, and 13 in a direction perpendicular to the plane of a drawing sheet. The

birefringent plate 11 separates the incident light into an ordinary ray and an extraordinary ray, and its main surface 14 extending perpendicularly from the plane of the drawing sheet where the ordinary ray and the extraordinary ray exist makes an angle of substantially 45 degrees with respect to a horizontal scanning direction H. The birefringent plate 12 has its main surface 15, where the ordinary ray and the extraordinary ray exist, substantially coinciding with the horizontal scanning direction. The birefringent plate 13 has its main surface 16 making an angle of substantially -45 degrees with respect to the horizontal scanning direction H. These three birefringent plates 11, 12, and 13 are superposed on each other so that the second birefringent plate 12 is situated between the remaining birefringent plates, and these are arranged in an incidence optical path so that the first or third birefringent plate comes closest to a solid-state image pickup element. The following description is given on the assumption that the third birefringent plate is disposed closest to the solid-state image pickup element. Additionally, the angle between the main surfaces of the three birefringent plates 11, 12, and 13 is relative, and a method for measuring the angle may be

performed either clockwise or counterclockwise.

Next, a description will be given of a general solution of a separation distance by which the incident light is separated by the three birefringent plates in this embodiment.

If a separation distance between the ordinary ray and the extraordinary ray by the first and third birefringent plates is represented as d_1, and a separation distance between the ordinary ray and the extraordinary ray by the second birefringent plate is represented as d_2, and the following condition is established

$$\frac{d_2}{\sqrt{2}} < d_1 < \sqrt{2}d_2,$$

a result obtained by allowing the incident light to be separated by the aforementioned combination of these three birefringent plates will be as shown in Fig. 2. In detail, one incident beam of light admitted to the origin of Fig. 2 is separated by distance d_1 in the direction of 45 degrees with respect to the horizontal scanning direction by the first birefringent plate 11 (shown by a solid-line arrow in Fig. 2) and is changed into two rays, each having the same intensity. Thereafter, these rays are separated by distance

d_2 in parallel with the respective horizontal scanning directions by the second birefringent plate 12 (shown by a broken-line arrow in Fig. 2) and is changed into four rays, each having the same intensity. Thereafter, these four rays are separated by distance d_1 in the direction of -45 degrees with respect to the respective horizontal scanning directions by the third birefringent plate 13 (shown by an alternate long and short dashed line arrow in Fig. 2) and are finally separated into eight rays 21 to 28, each having the same intensity, as shown in Fig. 2.

The thus formed embodiment can be regarded as a combination of an optical low-pass filter that separates the ordinary ray and the extraordinary ray from each other by a distance of d_2 in the horizontal direction H as shown in Fig. 3 (A) and an optical low-pass filter that separates one ray into four rays occupying the vertex positions of a rhombus having a length of

$$d_1 / \sqrt{2}$$

as shown in Fig. 3 (B). The optical low-pass filter shown in Fig. 3 (A) has a frequency characteristic of a cos curve that has a trap point at a point, which is odd-number times as large as

$$\frac{1}{2} \bullet \frac{P_x}{d_2} \left(= f_{x\infty 1}\right)$$

of a horizontal frequency normalized by $P_x / 2\pi$. The optical low-pass filter shown in Fig. 3 (B) has, in the horizontal direction, a frequency characteristic of a $\cos^2$ curve that has a trap point at a point, which is odd-number times as large as

$$\frac{1}{2} \bullet \frac{P_x}{d_1 / \sqrt{2}} \left(= f_{x\infty 2}\right)$$

and has, in the vertical direction, a frequency characteristic of a $\cos^2$ curve that has a trap point at a point, which is odd-number times as large as

$$\frac{1}{2} \bullet \frac{P_y}{d_1 / \sqrt{2}} \left(= f_{y\infty 1}\right).$$

Therefore, the frequency characteristic in the horizontal direction of the optical low-pass filter of the aforementioned embodiment has a characteristic of

$$\cos \bullet \frac{f_x}{f_{x\infty 1}} \bullet \frac{\pi}{2} \times \cos^2 \frac{f_x}{f_{x\infty 2}} \bullet \frac{\pi}{2}$$

and has a characteristic of

$$\cos^2 \frac{f_y}{f_{y\infty 1}} \bullet \frac{\pi}{2}$$

in the vertical direction.

Next, a description will be given of characteristics in a case in which values of d_1 and d_2 are determined in this embodiment so that desirable horizontal and vertical frequency characteristics can be obtained when P_x and P_y are substantially equal to each other as has been cited in the prior art problem.

If

$$d_2 = P_x, d_1 / \sqrt{2} = \frac{2}{3} \bullet P_x$$

(therefore,

$$d_1 = \frac{2\sqrt{2}}{3} \bullet d_2 = 0.943 d_2$$

, which greatly differs from the conventional one

$$d_1 = d_2 / \sqrt{2} = 0.707 d_2)$$

the following equations will be obtained

$$f_{\infty x1} = 1/2, f_{\infty x2} = \frac{1.5}{2}, f_{\infty y2} = \frac{1.5}{2}$$

, in which a horizontal frequency characteristic is a characteristic of the curve 41 obtained by a combination of a curve of

$$\cos \frac{f_x}{f_{x\infty 1}} \bullet \frac{\pi}{2}$$

shown in the curve 42 of Fig. 4 (A) and a curve of

$$\cos^2 \frac{f_x}{f_{x\infty 1}} \bullet \frac{\pi}{2}$$

shown in the curve 43. Accordingly, a cutoff characteristic near the ideal characteristic (re-showing the curve of Fig. 7 (A)) shown in the curve 40 is obtained like the characteristic (re-showing the curve 93 of Fig. 9 (A)) of the conventional example

$$\left(d_2 = P_x,\ d_1 = d_2 / \sqrt{2} \right)$$

shown in the curve 44.

Additionally, a frequency characteristic in the vertical direction becomes identical to the characteristic shown in the curve 51 of Fig. 4 (B), which is a characteristic near the ideal characteristic shown in the curve 50 of this figure, in comparison with the conventional characteristic (re-showing the curve 101 of Fig. 10) shown in the curve 52 of the figure.

A general solution of the aforementioned examples will be considered. Unlike the conventional examples in which a fixation is made to

$$d_1 = d_2 / \sqrt{2} = P_x / \sqrt{2}$$

and, accordingly, to

$$f_{x\infty 2} = 2 \bullet f_{x\infty 1}, \ f_{y\infty 1} = \frac{P_y}{P_x} \bullet 2f_{x\infty 1},$$

d_1 is determined giving consideration also to the value of P_y so as to obtain a value of $f_{x\infty 1}<f_{x\infty 2}<2 \cdot f_{x\infty 1}$ in the present invention. Therefore, the relation

$$f_{y\infty 1} = \frac{P_y}{P_x} \bullet f_{x\infty 2} < \frac{P_y}{P_x} \bullet 2f_{x\infty 1}$$

can be established, and the frequency characteristic in the vertical direction can be changed to a value near the ideal characteristic, thus making it possible to obtain a characteristic having excellent frequency characteristics both in the horizontal direction and in the vertical direction.

As the general solution, a desired range of the value of d_1 is as follows. That is, if $f_{x\infty 2}$ is set to be a value smaller than $f_{x\infty 1}$, a characteristic in an originally-to-be-passed frequency area of a frequency characteristic in the horizontal direction will be deteriorated (passing power becomes too small), and therefore it is practical to set the value to be a value of $1/2=f_{x\infty 1}<f_{x\infty 2}$.

By rewriting this condition to the relationship among d_1, d_2, and P_x,

$$d_1 < \sqrt{2}\, d_2 \simeq \sqrt{2}\, P_x$$

is obtained. As has been described in "prior art" of this specification, a problem will occur if $f_{x\infty 2}=2 \cdot f_{x\infty 1}$ as in the conventional examples, and there is a need to establish the relation $f_{x\infty 2}<2 \cdot f_{x\infty 1}$, and therefore a desired relationship among d_1, d_2, and P_x including this condition is expressed as

$$d_2/\sqrt{2} < d_1 < \sqrt{2}\, d_2 \simeq \sqrt{2}\, P_x.$$

In the description provided above, although an example, in which $d_2 \simeq P_x$ and, accordingly, $f_{x\infty 1}=1/2$, has been taken, a horizontal direction passing characteristic is excessively deteriorated (passing power becomes small) if $f_{x\infty 2}$ approaches $f_{x\infty 1}$ at this time. Therefore, in order to prevent this, the value of $f_{x\infty 1}$ is made slightly greater than 1/2 (therefore, d_2 is made slightly smaller than P_x), thereby making it possible to achieve the cutoff characteristic without being excessively deteriorated.

Effect of the Invention

As described above, according to the present invention, an optical low-pass filter having excellent characteristics

both in the horizontal direction and in the vertical direction can be obtained, and a characteristic especially in the vertical direction can be improved in comparison with the prior art characteristic, and it is possible to improve the image quality of a solid-state image pickup camera, especially the image quality of a camera using a solid-state image pickup element in which the number of pixels in the horizontal direction is relatively large.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Fig. 1 is a schematic diagram used to explain optical properties of each birefringent plate used in an embodiment of the present invention, Fig. 2 is an explanatory drawing that shows a situation in which incident light is separated by the present invention, Fig. 3 is an explanatory drawing of optical properties of this embodiment, Fig. 4 is an optical frequency characteristic diagram of this embodiment, Fig. 5 is an enlarged plan view of an example of an opening pattern of a CCD solid-state image pickup element to which the present invention is applied, Fig. 6 is a spatial frequency spectrum diagram obtained by this CCD solid-state image pickup element, Fig. 7 is a characteristic diagram that shows an ideal characteristic of an optical low-pass filter needed for this

CCD solid-state image pickup element, Fig. 8 is an explanatory drawing that shows a situation of light separation by a conventional optical low-pass filter, and Fig. 9 and Fig. 10 are frequency characteristic diagrams of this conventional optical low-pass filter.

11 ... First birefringent plate, 12 ... Second birefringent plate, 13 ... Third birefringent plate.

Fig. 1

11 First birefringent plate
12 Second birefringent plate
13 Third birefringent plate
14 Main surface
15 Main surface
16 Main surface

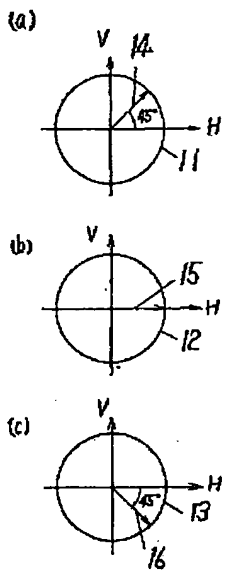


Fig. 2

21-28 Ray

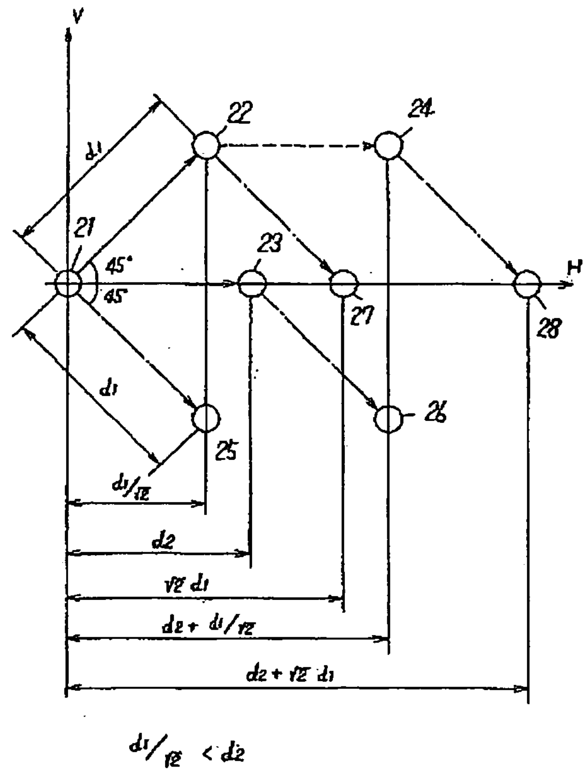


Fig.6

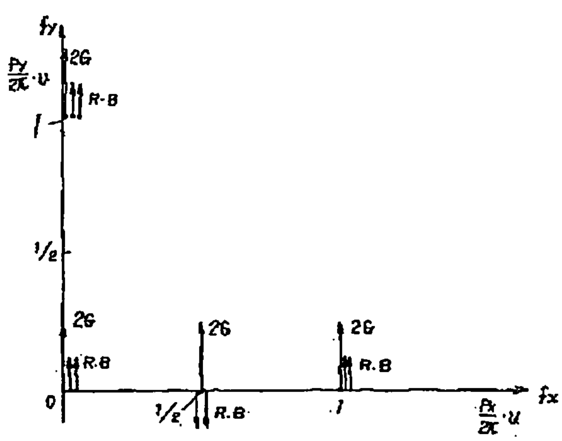


Fig. 10

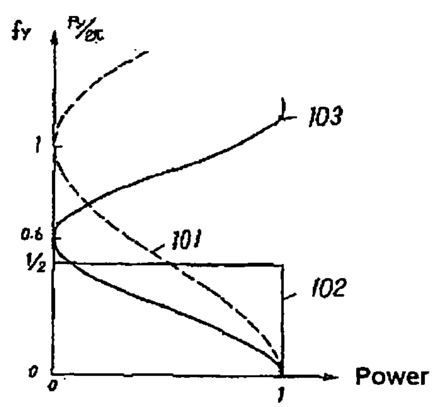


Fig.3

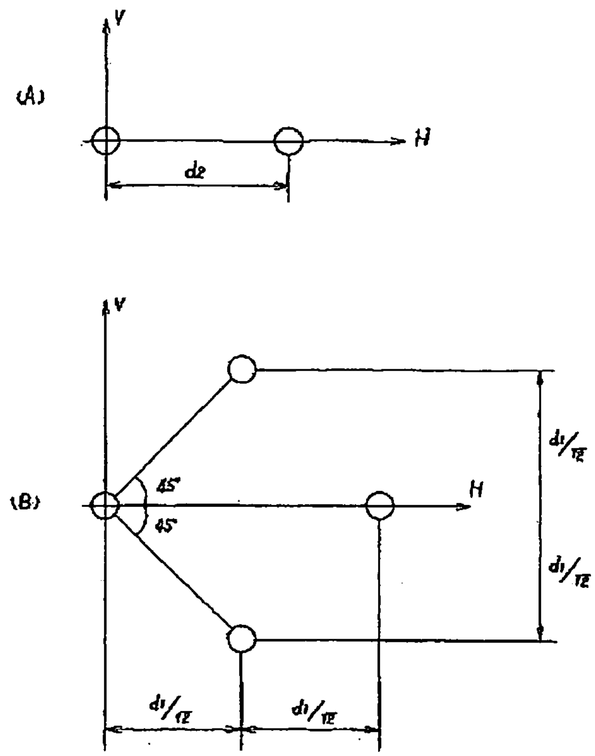


Fig.8

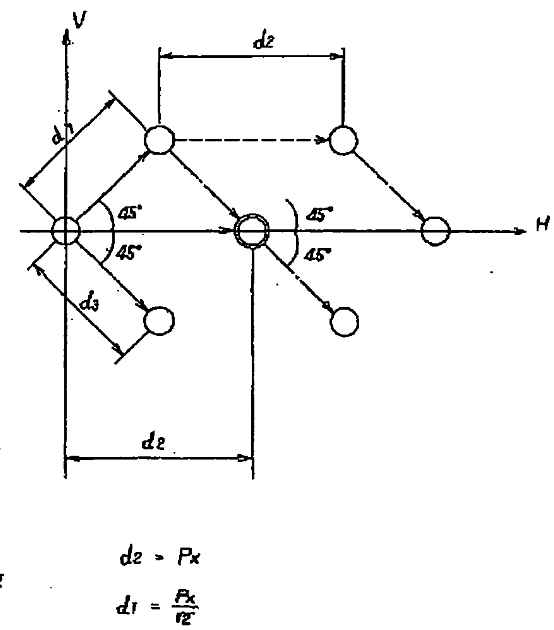


Fig.5

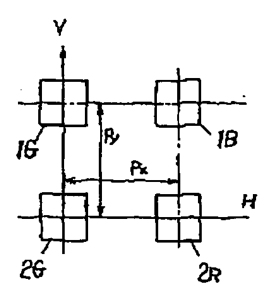


Fig. 4

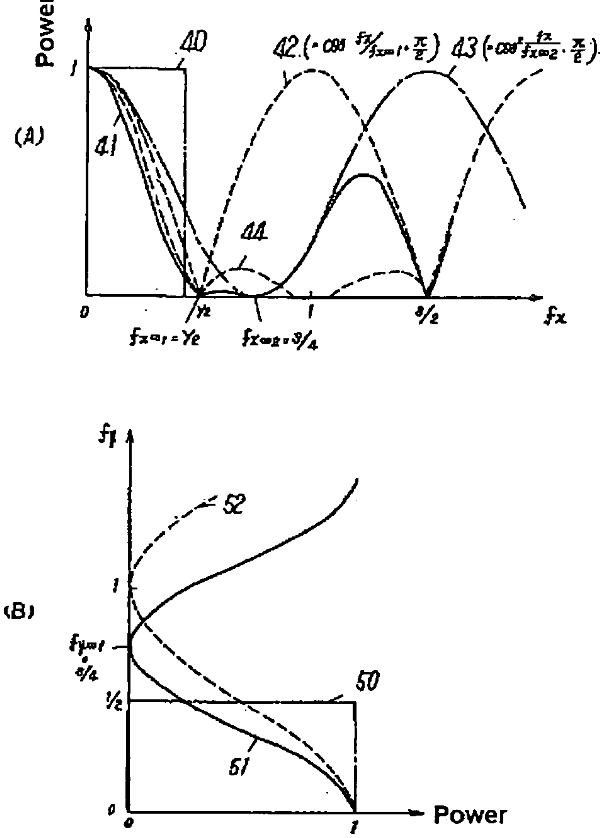
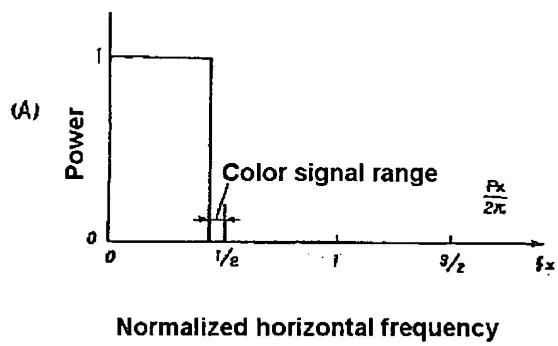
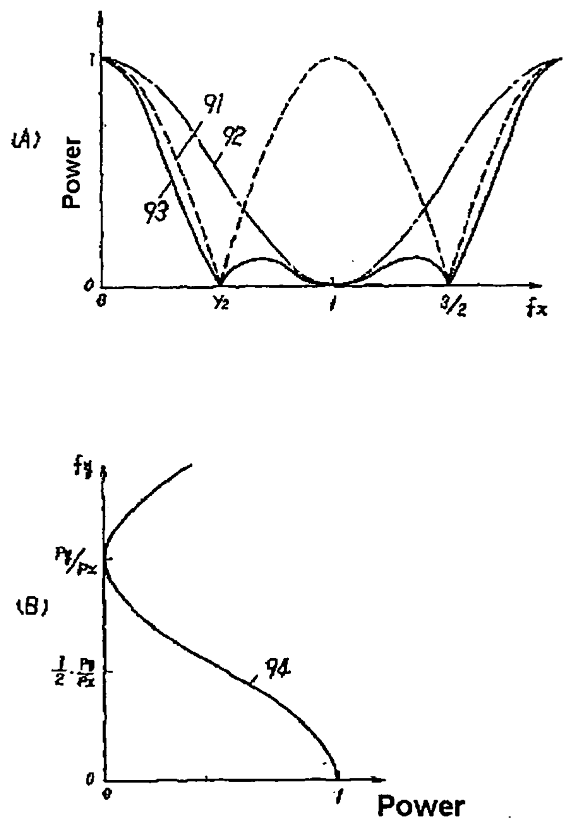


Fig. 7



(A)
Power
Color signal range
1
0
0
1/2
1
3/2
fx
Px/2π
Normalized horizontal frequency
(B)
fy
Py/2π
1
1/2
0
0
1
Power

Fig.9



(A)
Power
91
92
93
1
0
0
1/2
1
3/2
fx
(B)
fy
Py/Px
1/2 · Py/Px
94
0
0
1
Power